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Ship Systems Integration & Design Department

Technical Report

Mulberry 21:
Rapidly Deployable and Recoverable Harbor

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14. ABSTRACT

After landing on the beaches of Normandy during World War II, the Allies needed means to move necessary equipment over the secured beachhead and to the front lines. The answer was the Mulberry Harbor. A modern concept design of the harbor has been undertaken to overcome the limitations of the original design and meet new operating requirements. The Mulberry 21 design will be fast to deploy, easily recovered, and able to survive in higher sea states. The harbor system consists of an elevated causeway and inflatable breakwater. The inflatable breakwater arrives in theater stored flat on a roll and is deployed from the stern of a ship. It is unrolled and anchored as the ship advances. The breakwater is sunk and inflated with seawater using a high volume pump. Once the breakwater has been installed, the causeway is lowered from a ship and towed into place. After being secured, the causeway is jacked up with inflatable bags in sequence until the roadway is safely out of the water. Mulberry 21 provides a fully moored breakwater and elevated causeway that can be installed quickly and allows ship to shore cargo movement to unimproved beach areas.

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Abstract

After landing on the beaches of Normandy during World War II, the Allies needed means to move equipment over the beachhead, to the front lines. The answer was the Mulberry Harbor.

A concept design has been undertaken to overcome the limitations of the original design and meet new operating requirements.

The Mulberry 21 design will be faster to deploy, easily recovered, and able to survive in higher sea states. The harbor system consists of an elevated causeway and inflatable breakwater. The inflatable breakwater arrives in theater stored flat as a roll and is deployed from the stern of a ship. It is unrolled and anchored as the ship advances. The breakwater is sunk and inflated with seawater using a high volume pump.

Once the breakwater has been installed, the causeway is lowered from a ship and towed into place. After being secured, the causeway is jacked up with inflatable bags in sequence until the roadway is safely out of the water. Mulberry 21 provides a fully moored breakwater and elevated causeway that can be installed quickly and allows ship to shore cargo movement to unimproved beach areas.

Authors

This report is the culmination of work conducted by students employed under the National Research Enterprise Intern Program sponsored by the Office of Naval Research. This program provides an opportunity for students to participate in research at a Department of Navy laboratory for 10 weeks during the summer. The goals of the program are to encourage participating students to pursue science and engineering careers, to further education via mentoring by laboratory personnel and their participation in research projects, and to make them aware of Navy research and technology efforts which can lead to future employment.

At the Naval Surface Warfare Center Carderock Division, the single largest employer of summer interns is the Center for Innovation in Ship Design (CISD), which is part of Carderock's Ship Systems Integration and Design Department. The intern program is just one initiative in which CISD fulfills its chartered role of conducting student outreach and developing future naval ship designers.

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Executive Summary

Mulberry 21 is the name for concept design replicating the capabilities of the original Mulberry Harbors used during World War II to establish ports on D-Day beaches. The original Mulberry Harbor used concrete caissons and scuttled ships to create a breakwater and shelter the harbor from the open ocean. A floating causeway was developed to create a way to get cargo through the surf and to the beach. Mulberry 21 aims to redevelop the concept of a quickly deployable harbor ab initio using 21st century technology.

The Mulberry 21 is a system of systems, consisting of breakwater and causeway sub-systems. The breakwater is an inflatable structure made of advanced composites and fabric. The deflated breakwater is stored flat on rolls that fit into ISO shipping containers. When prepared for deployment, the breakwater is unrolled from the stern of a ship and sunk to the bottom using steel ballast cables imbedded in the bottom of the breakwater. The breakwater is then filled and pressurized by pumps with seawater to create a water-filled barrier that provides protection from incoming waves. To recover the system, the process is reversed by pumping out the water and re-spooling the depressurized breakwater sections.

Each breakwater section is 100 feet long. The breakwater's fabric is a polyester weave coated with a vulcanized rubber that creates a rugged, watertight, lightweight structure that is resistant to seawater and UV deterioration. The structure is stiffened with carbon fiber bars to maintain the shape of the breakwater. A 12,000 GPM pump mounted on a floating pontoon fills the structure with water. The pumps will be mounted on both ends of every nine sections of breakwater. The section of the breakwater is inflated from the seafloor, which is initially sunk by steel ballast cables. The reduced seaway in the harbor then allows for the subsequent installation of the causeway system.

The causeway system is deployed after the breakwater is in place. The sections are lowered from the transporting ship and connected together. The sections are joined using a pneumatic piston-activated ball locking system. Once in place, water bags are lowered to the bottom via a centrally installed winch and inflated with seawater, jacking the sections out of the surf zone. The bottom of the column is weighted and moored by an anchored steel foot. The remaining lift capacity of the lift bags is provided by inflation using compressed air. Each section is held rigidly in place by a winch tensioning system in the column and three anchors. The anchors are either a spiral screw for soft bottoms or small explosive embedment anchors for solid surfaces.

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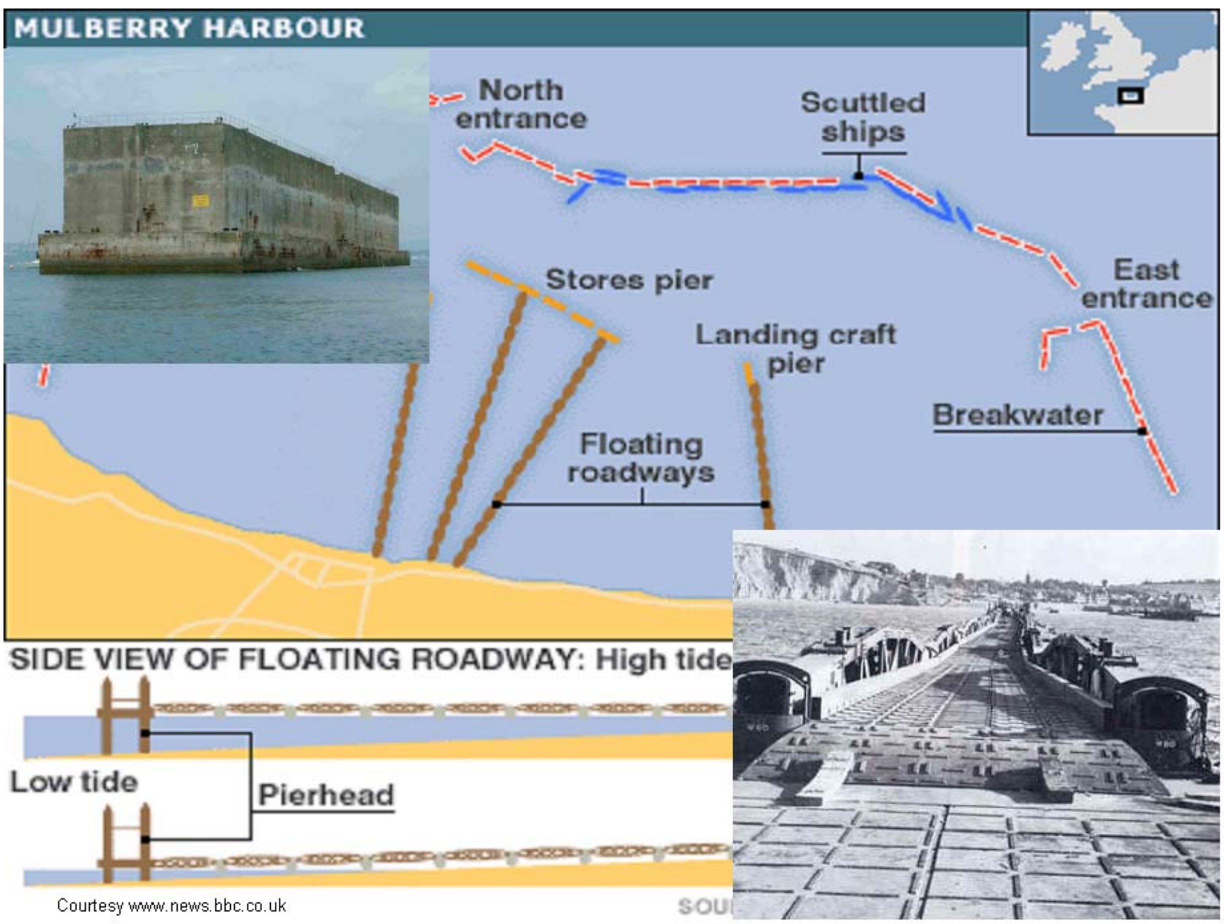
1.0 Introduction

The objective of this project was to conceptually design a rapidly deployable harbor system that can be deployed from a sealift ship. The harbor needs two sub-systems, a breakwater and a causeway system; the breakwater to calm the`` harbor and protect the causeway from the open sea and the causeway to bridge the surf zone.

The system must withstand all weather conditions and meet the transport requirements of the Marine Expeditionary Force. The harbor must handle a ship of 450 feet long with a 15-foot draft. The beach is assumed to be secure. It is also desirable that the system can be recovered and deployed multiple times. The causeway system must be adaptable to a variety of beach slopes and coastlines.

The concept stems from the Mulberry Harbors of World War II. Mulberry A and B were temporary harbors deployed on the beaches of Normandy to aid in transfer of troops and cargo. They were set up in three days using concrete caissons and scuttled ships to act as a breakwater and a floating roadway deck to act as a causeway. Mulberry A set up by U.S. Forces only lasted a few weeks because of poor mooring in a storm. Mulberry B lasted the duration of the war because the British forces had a proper mooring system. Some parts of the Mulberry are still in place today. A depiction of the setup of Mulberry B is shown in Figure 1.

Figure 1: Mulberry Harbor B at Arromanches, France



2.0 Design Evolutions

2.1 Breakwater

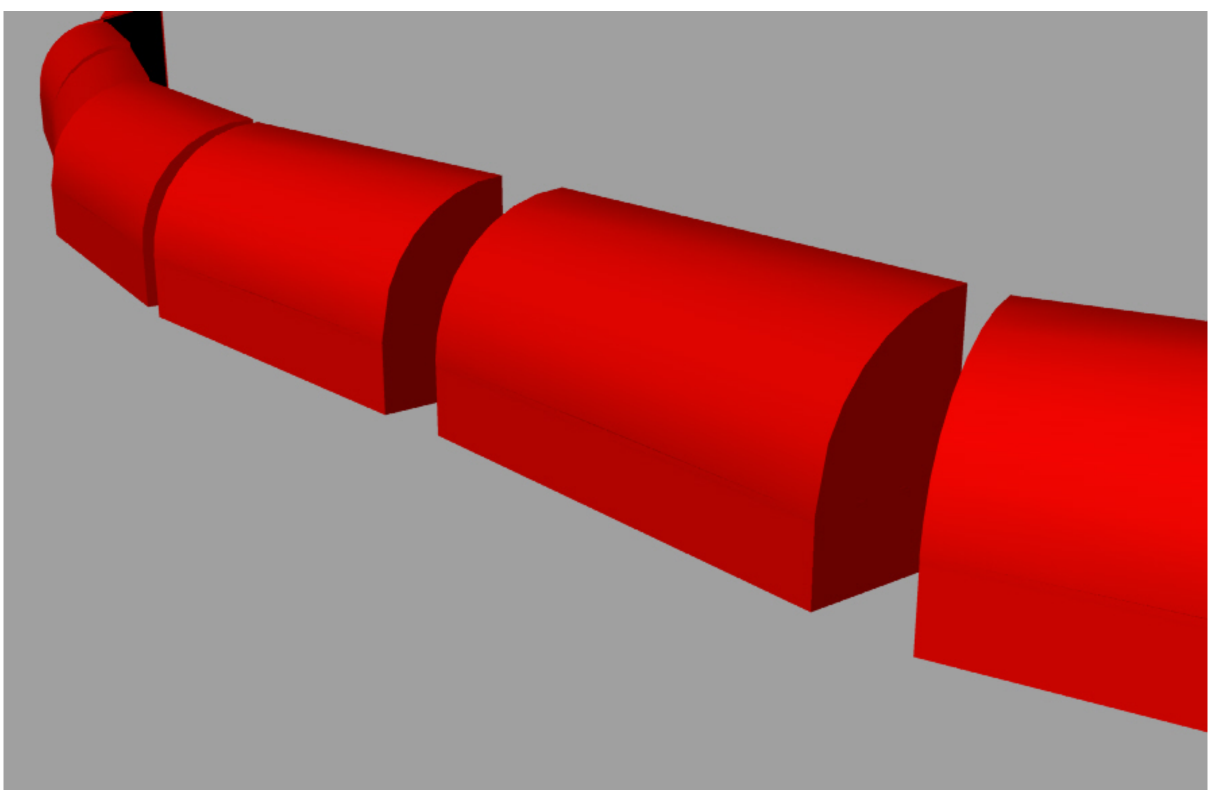
The Mulberry 21 harbor was designed in two parts: the causeway and the breakwater. Many concepts were prepared for the breakwater but dismissed in the very early stages due to their inherent complexity or technical issues.

An inflatable breakwater was chosen because of its simplicity, ease of deployment, and lightweight transport. All other concepts were judged to be too heavy and complicated.

The breakwater's first design was a long, continuous seawater filled semi-circular profile tube that had a design length of about 900 feet. The profile shape was adjusted to a quarter-circle with a rectangular base to reduce the seawater needed to fill the structure. The advantage of the quarter circle shape is that it helps to promote the breaking of waves over the structure instead of transmitting energy through the structure. Cables are embedded in the base of the structure to sink the fabric structure to the seafloor for inflation.

To make handling of the breakwater more practical and versatile the individual section length was cut to 100 feet. For every 9 sections, there are two 12,000 GPM pumps to fill and maintain pressure in the breakwater. Carbon fiber shaping bars were added to ease the pressure on the fabric and maintain the shape of the breakwater. The breakwater is rolled off the stern of a ship for deployment and recovered in a similar manner. The final design concept is pictured in Figure 2.

Figure 2: Breakwater Design



2.2 Causeway

The causeway system went through several design iterations before deciding on the final design concept as shown in Figure 3 and Figure 4.

Figure 3: Jack-Up Barge Concept

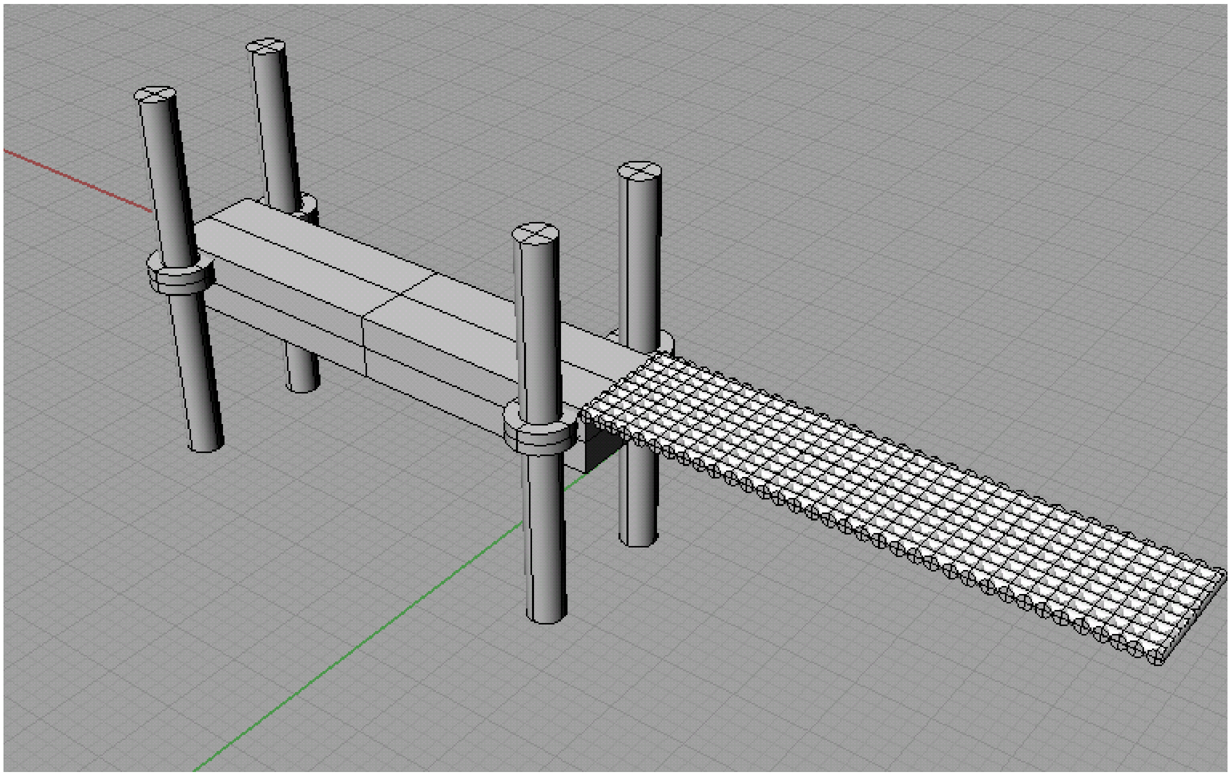
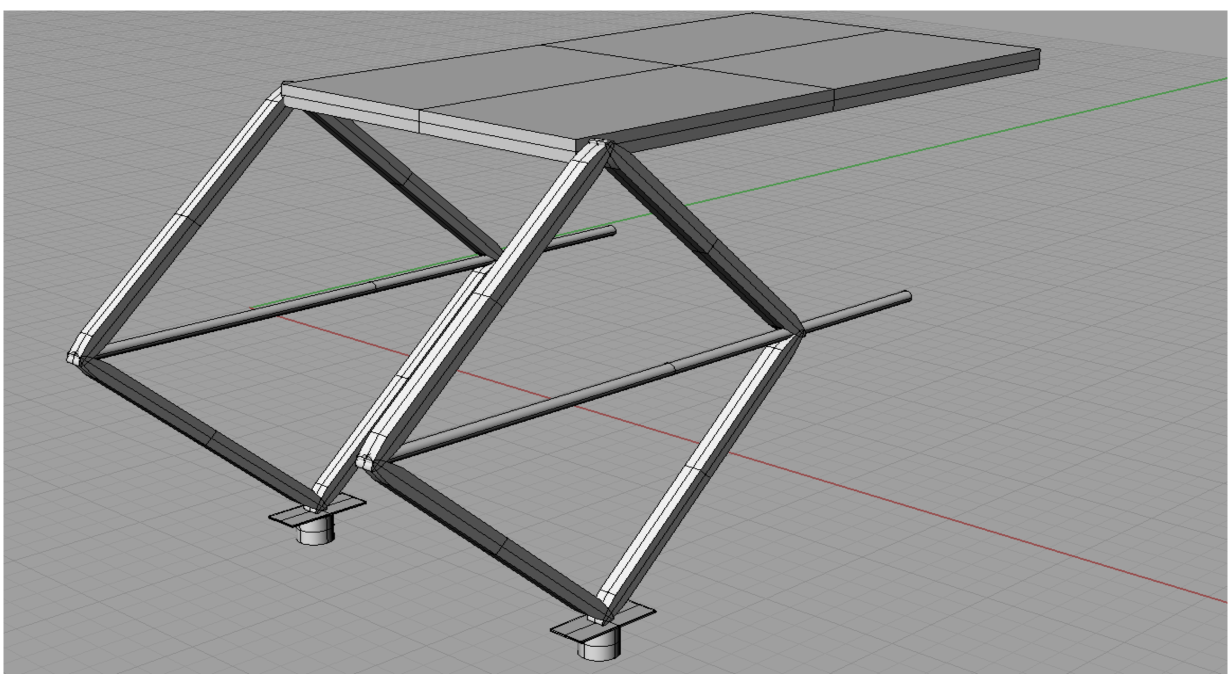


Figure 4: Jack-Screw Concept

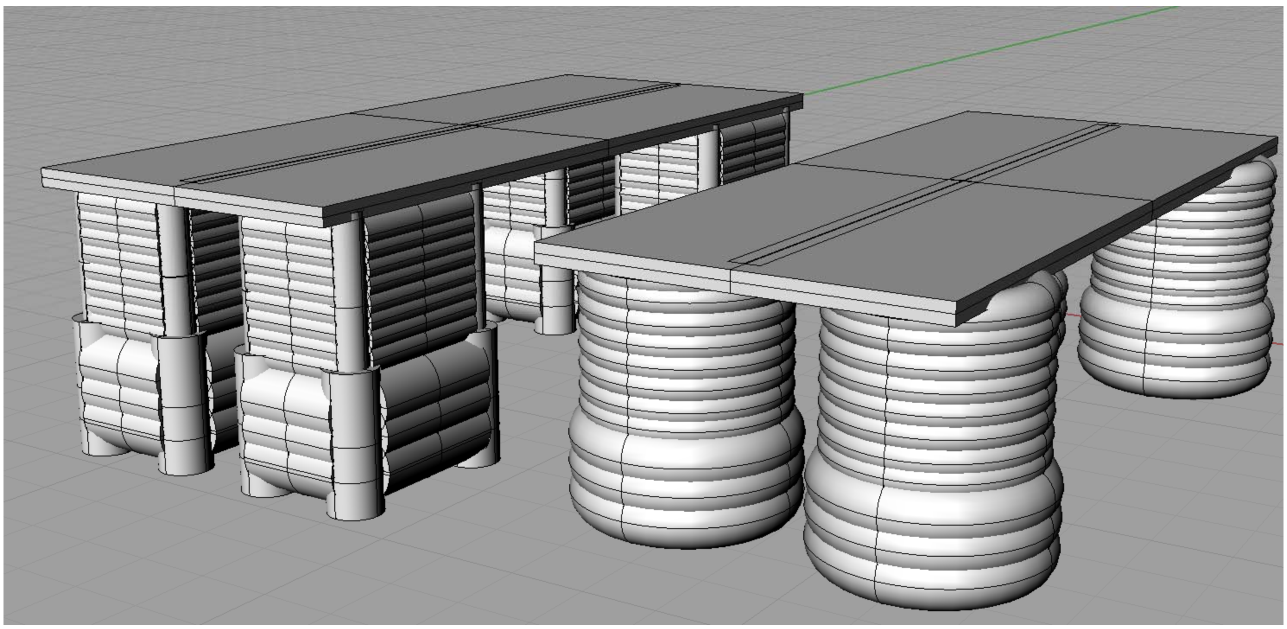


The design concept selected was based on the use of lift bags to elevate the causeway out of the surf zone as shown in Figure 5. The low pressure, high surface area bags create a high supporting force while in compression. The concept is based on aircraft recovery cushions, designed to lift an aircraft fuselage in the event of an accident.

When deflated the system is practically flat and can be easily stacked. Using fabric instead of steel also saves on system weight.

Water would fill the lower bags to act as an anchor. Air would fill the rest of the system to lift the roadway. The actual roadway deck is constructed of pultrusion fiberglass. This was chosen over steel to reduce weight. The roadway section’s dimensions would be 80 feet by 24 feet by 1.75 feet thick to remain similar in deck area to the current Improved Navy Lighterage System.

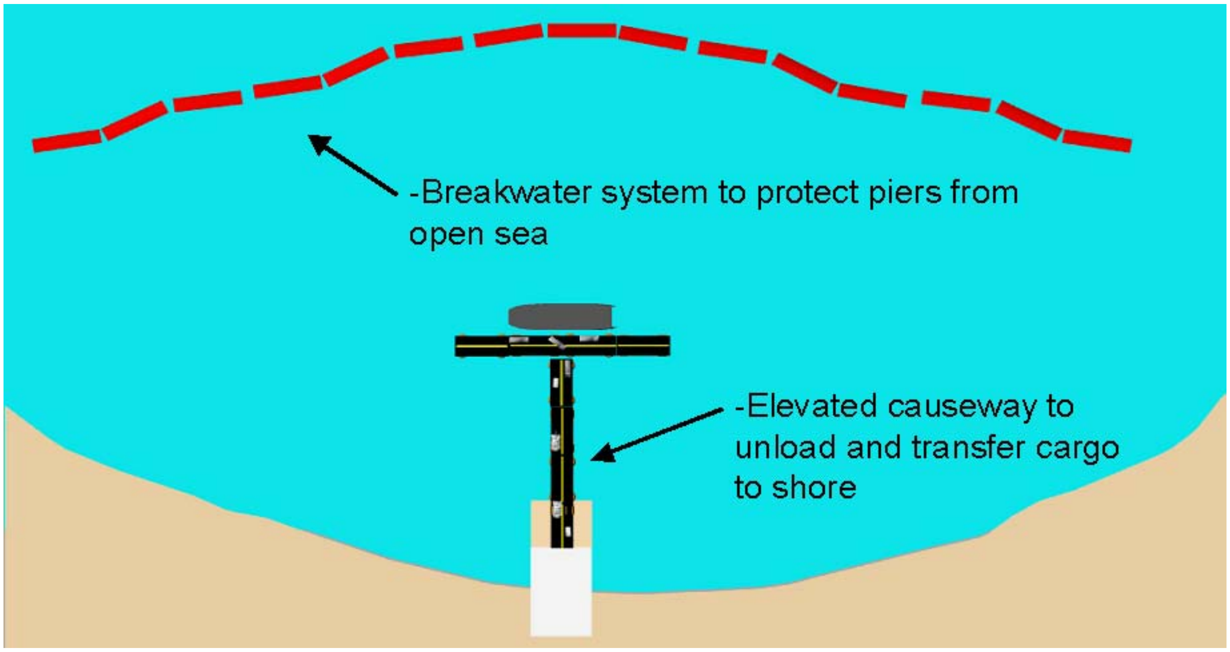
Figure 5: Final Design; Lift Bag Concept



3.0 Design

The design of the Mulberry 21 harbor system calls for the need of two sub-systems (Figure 6). The breakwater is the first sub-system. The breakwater is used to calm the harbors waters and protect the causeway from the open sea. The causeway is used to bridge the surf and allow cargo transport from ship to shore.

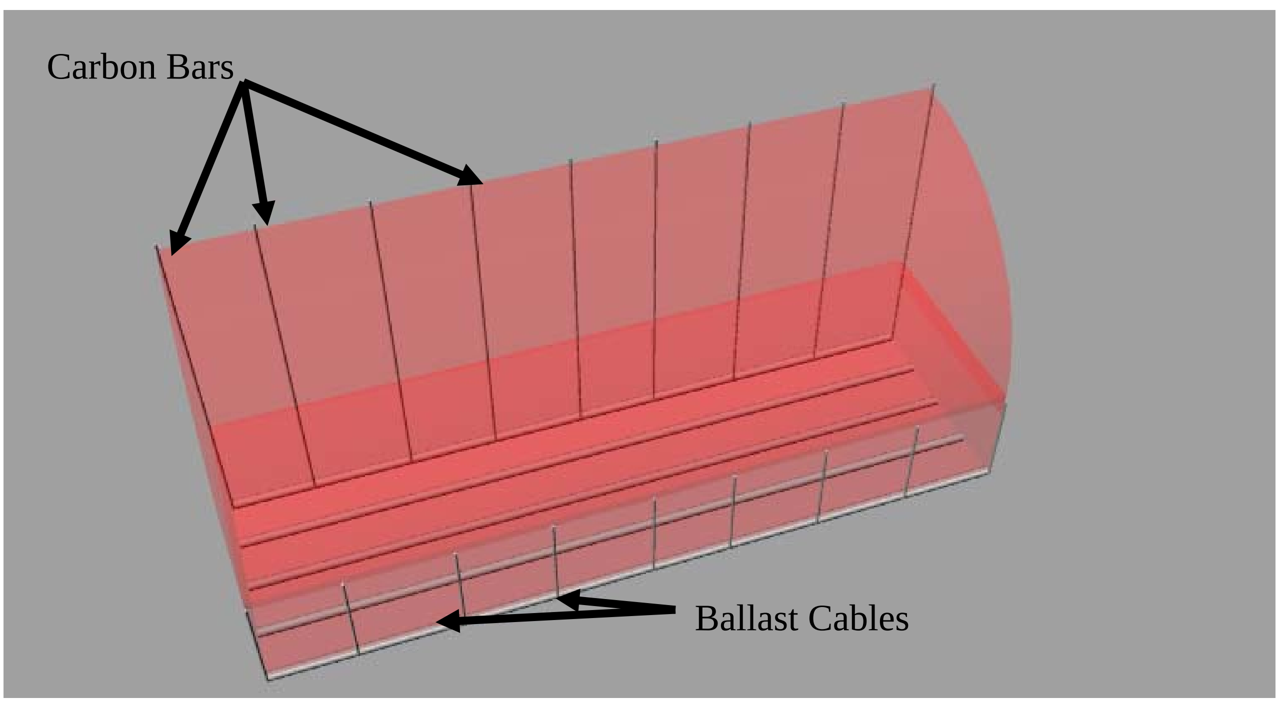
Figure 6: Harbor Overview



3.1 Breakwater

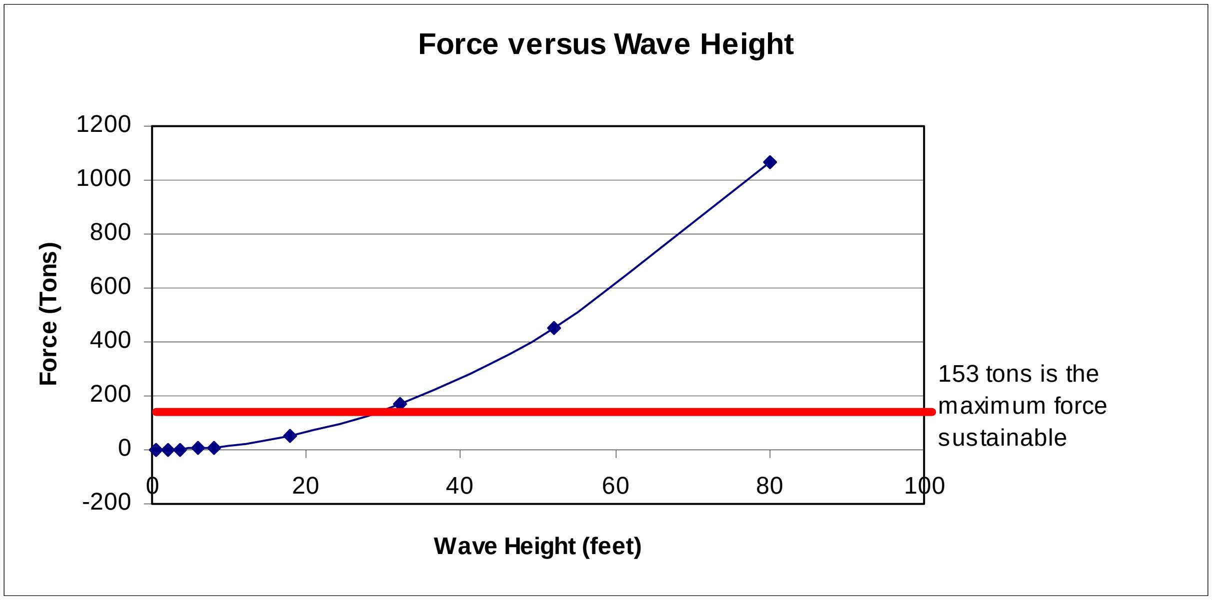
The long breakwater is the wall that protects the causeway and anything inside the harbor from the open sea. It is designed to absorb and disperse wave energy. Waves can exert huge forces on the breakwater and the breakwater must disperse the energy to protect the harbor. Table 4 details the forces that the breakwater must overcome. Figure 7 shows the breakwater section, which includes the ballasting cables and the carbon fiber shaping bars.

Figure 7: Final Breakwater Design



The 100 foot long breakwater segments have a quarter circle section with a rectangular base profile. The selected profile resists a turning force of 153 tons, equivalent to a 28-foot wave as shown in Figure 8. Anchoring would create a much higher sea state protection.

Figure 8: Comparison of Wave Energy to Rollover Force;



A length of 100 feet was chosen because it was the upper limit able to be handled, based on the weight of the material and the size of the coil when the breakwater is retracted. When coiled, with a 1-foot center support, the material creates a coil approximately 56 inches in diameter. Table 1 shows the size comparisons of different size rolls.

Table 1: Breakwater Roll Comparisons

Perimeter Profile (ft	Length (ft)	Roll Diameter (in)	Weight (lbs)
137.12	100	57	3,119
	200	79	6,238
	300	96	9,357

Material Choice

Several bag materials were researched and decisions were based on strength of the material, elasticity, and strength retention in seawater. Material strength was considered secondary to elasticity because of a few points. The pressures induced in the breakwater by over pressure and hydrostatic loading are relatively small, exerting low stresses. This would suggest researching materials with less strength, however the breakwater is reliant on the concept that when pressurized it will become rigid. The material cannot have a high elasticity or it will stretch and not be able to sustain the design loads.

Table 3 shows a few of the materials considered including the chosen material, Supreme Protector (UHMW-PE-512WE). Supreme Protector is a new material that is extremely strong, with very low strain. The only drawback to Superior Protector is that it is buoyant and thus requires anchor cables.

Kevlar and Zylon are good alternatives, and are not buoyant. They are also natural fibers, which are not resilient ultraviolet light or seawater environments.

Supreme Protector is now available in a rubber-coated version that can be heat sealed and sewn together at connecting points creating a strong watertight vessel. Burst strength was calculated with the hydrostatic pressure being 20 PSI, significantly less than the Supreme Protector's burst strength of 1000 PSI. Carbon bars were added to maintain shape. The breakwater sections are sub divided into three sections to aid damage survivability. A common tube connects these sections.

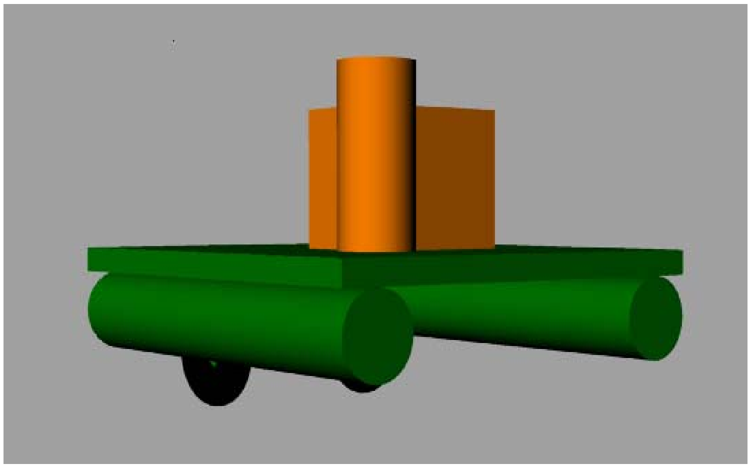
Table 2: Material Properties

Material	**Tensile Strength (Gpa)**	**Density (g/cm^3)**	**Elongation % (at failure)**	**Strength Retention% (in 3.5% NaCl after 6 months)**	**Strength Retention % (due to ultraviolet damage after 6 months)**
Zylon AS	5.8	1.54	3.5	90	35
Zylon HM	5.8	1.56	2.5	N/A	35
p-Aramid	2.8	1.45	2.4	100	N/A
m-Aramid	0.65	1.38	22	N/A	N/A
Steel Fiber	2.8	7.8	1.4	N/A	N/A
HS-PE	3.5	0.97	3.5	N/A	N/A
PBI	0.4	1.4	30	N/A	N/A
Polyester	1.1	1.38	25	N/A	N/A
Supreme Protector UHMW-PE-509WE	3.2	0.49	3	100	70
Supreme Protector UHMW-PE-512WE	4	0.27	3	100	70
Kevlar 29	3.6	1.44	3.6	100	N/A
Kevlar 49	3.6	1.44	2.4	100	N/A

Pump Selection

To inflate the breakwater, the pump needs the capacity to overcome thirty feet of water depth while supplying over 12,000 GPM. A commercially available representative pump is provided by Gator-Pumps. The pump is to be used on a floating trailer platform to the depth of thirty feet. This will fill nine 100 foot sections in about 12 hours. Two pumps would be added for nine sections for redundancy and to reduce fill time to six hours. A sketch of the pump is at Figure 9.

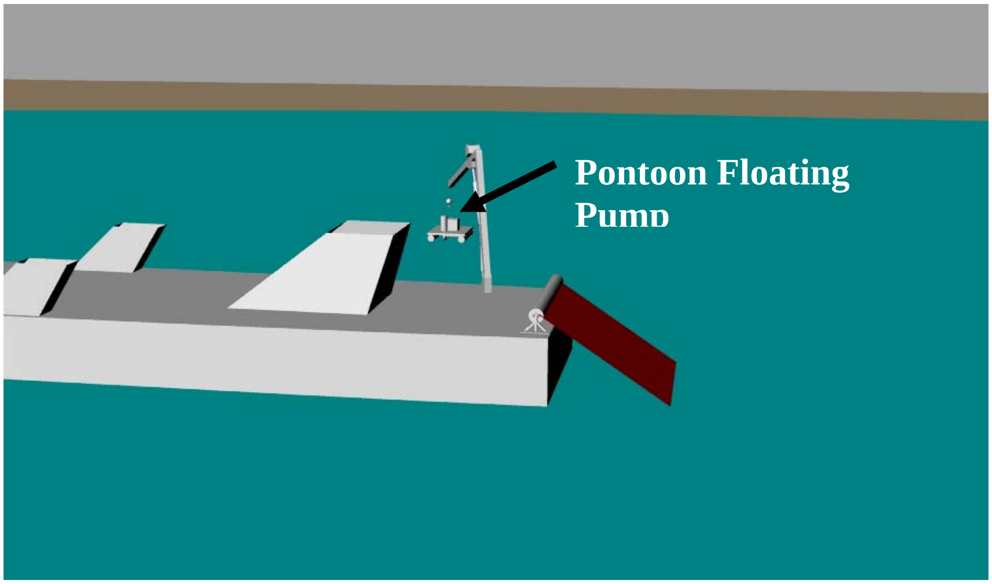
Figure 9: Pump Sketch



Breakwater Deployment

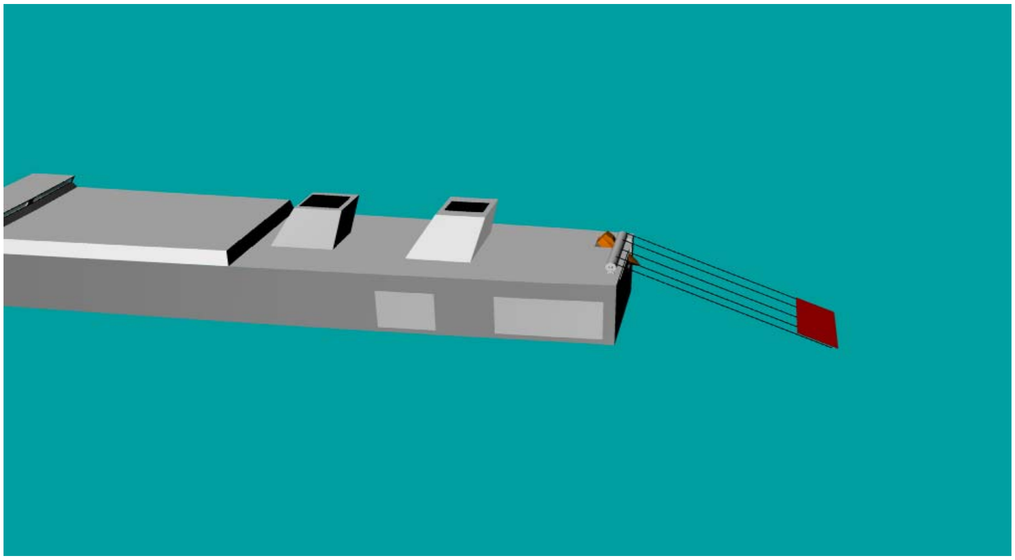
The breakwater deployment begins with arrival of the lift ship into the theater of operations. The breakwater is stored as coils in an FEU (Forty Foot Equivalent Unit). The breakwater section is removed from the FEU and brought to a stern ramp or stern deck. Anchors are dropped and the roll unspooled leaving the breakwater flat on the seafloor behind it. As the breakwater is deployed from the stern of the ship, the floating pontoon pump is also deployed with it (Figure 10).

Figure 10: Step 1 of the Breakwater Deployment.



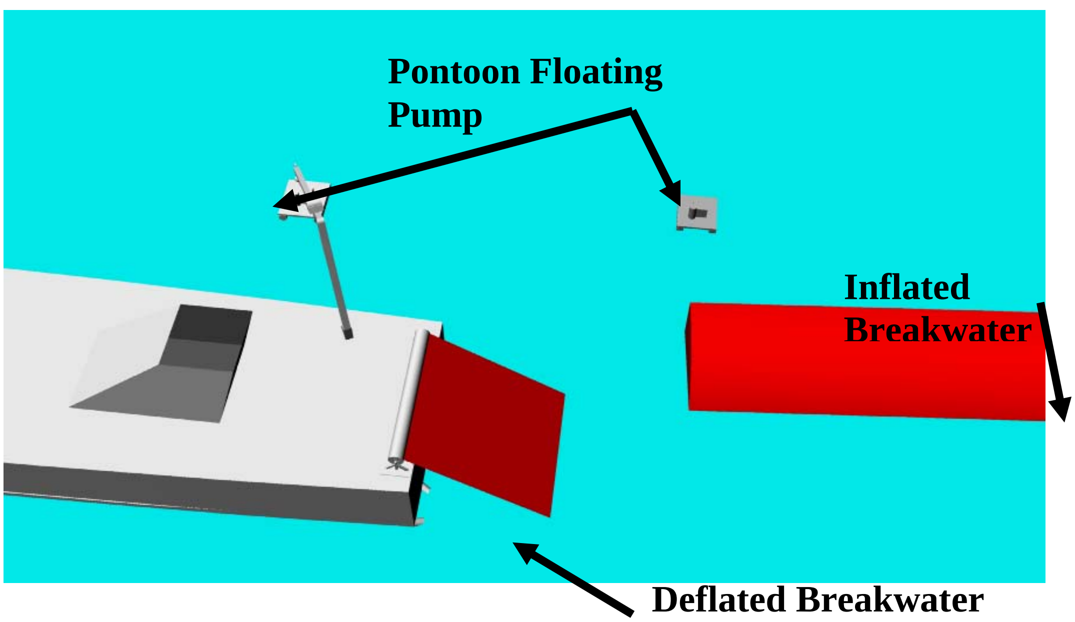
The floating 12,000 GPM pump is also off-loaded at both ends for every 9 sections to fill the breakwater. The anchor cables go beyond the edge of the section to aid in discharge and recovery. Anchor cables are the only connection point between the breakwater sections as shown in Figure 11.

Figure 11: Step 2 of the Breakwater Deployment



Each section holds approximately 960,000 gallons of seawater. The breakwater sections can be distributed to any configuration because of the relatively small length, making it adaptable to any coastline. This setup is depicted in Figure 12.

Figure 12: Step 3 of the Breakwater Deployment



3.2 Causeway

Roadway Barge Deck

The roadway deck uses composite materials to keep the sections lightweight and hence easily transportable. Each section has dimensions of 80 ft x 24 ft x 1.65 ft. The sections are made of a structural member consisting of a fiberglass material, created using a Pultrusion process to reduce cost when compared to other composites. The roadway grating deck, to alleviate point loading, is also made of Pultrusion. The composite material also minimizes the weight of the barge. These features are shown in Figure 16. The internal structure is a box frame with five horizontal stiffeners with a cross-section of 0.5m x 0.06m. The stiffeners are sandwiched between two Pultrusion plates the have a cross-section of 10m x .06m as shown in Figure 17. The Extren® deck plating is fastened to the top of this sandwich structure.

Figure 13: Causeway Roadway Diagram

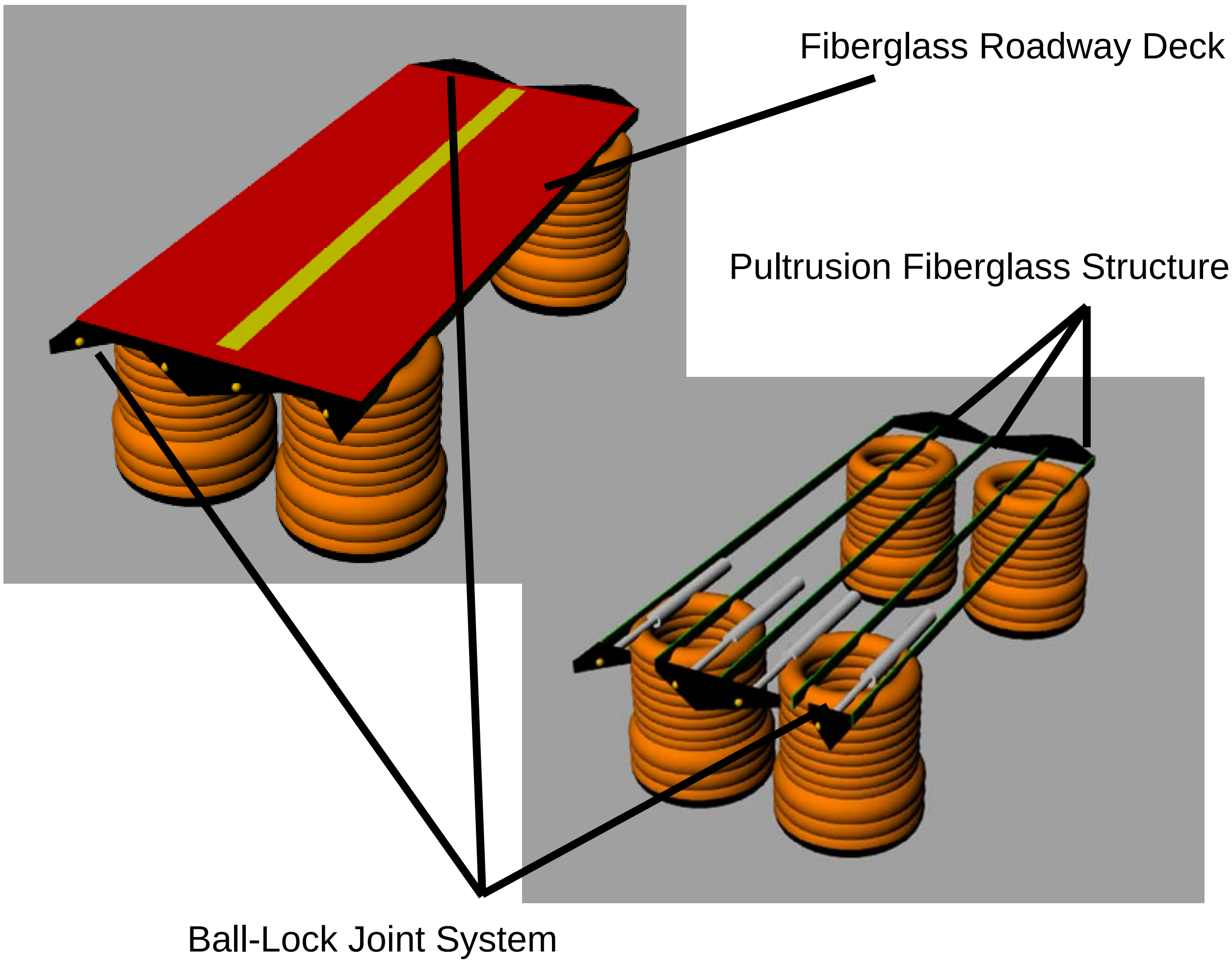
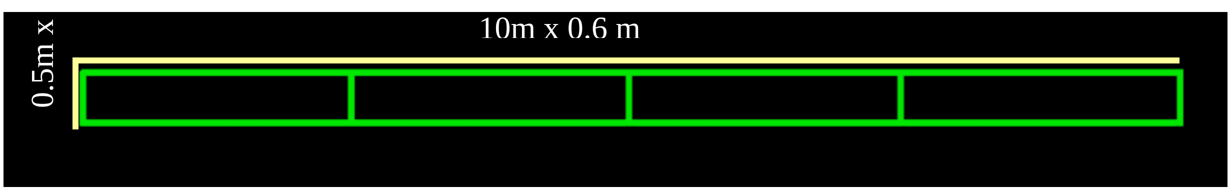


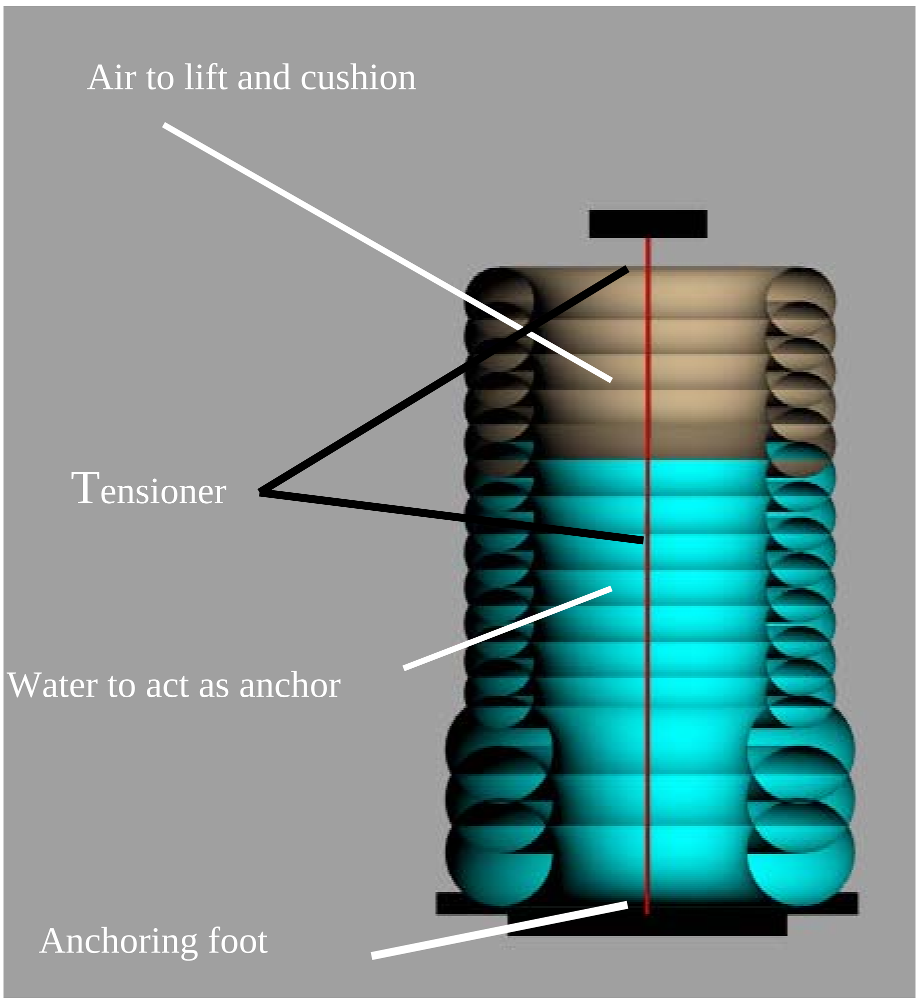
Figure 13: Cross-Section of Roadway Deck



Lifting Mechanisms

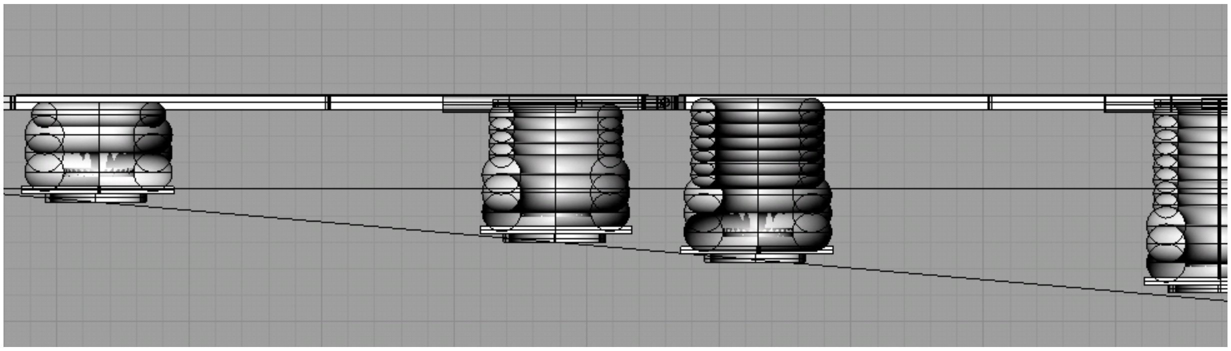
The causeway is raised out of the surf zone by a series of hybrid lift bags (Figure 13). The lift bags are extended from the floating barge roadway deck to the seafloor by a winch tensioning system and sunk by the attached steel anchor foot. The anchor foot is the area of the lift bag column and has a pipe attached to the bottom to create a small contact surface area with the seafloor. This anchors the bag and also provides support for the column. The bag is filled with water until the bag reaches above the surface, up to 8.8 meters in height under the current design. The radius of the column is 2.7 meters when inflated. Additional height is provided by compressed air in the bags. The lift capacity of these bags is 120 tons at 7 psi. The bags are filled sequentially using a pressure release valve. The bags are filled from the bottom, and a pressure valve opens once the desired 7 psi is obtained, allowing for the filling of the next bag. The tensioner keeps tension on the foot making the column a rigid structure. The bags are made from the same material as the breakwater; a vulcanized rubber coated Supreme Protector (UHMW-PE-512WE).

Figure 14: Lift bag Column Cross Section



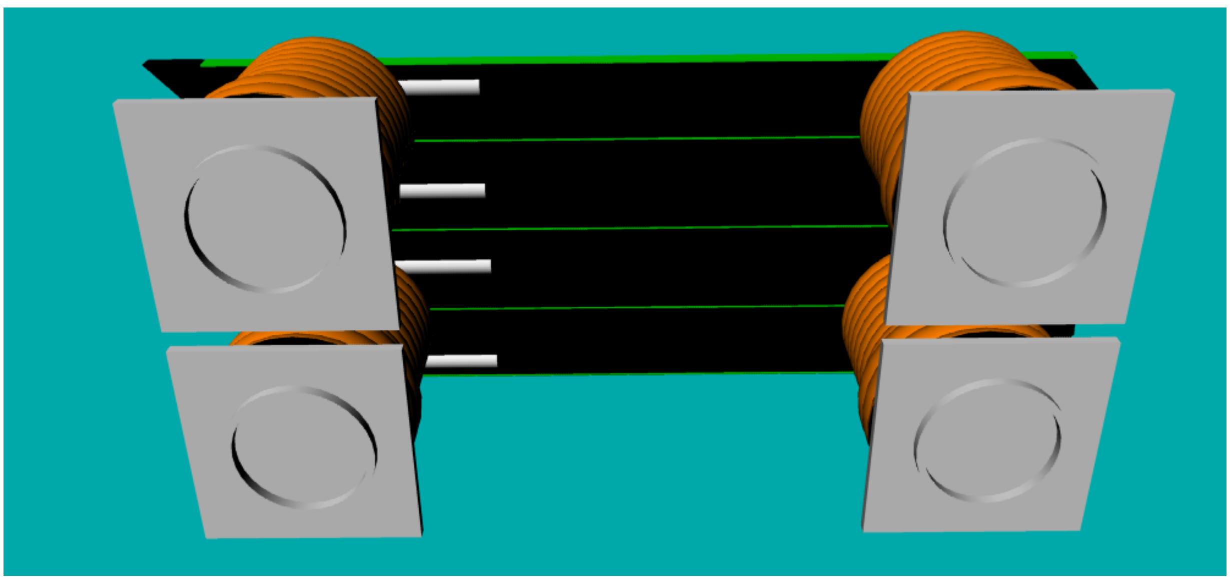
The adjustment to the slope of the beach results from filling the bags from the seafloor up, filling a different number of bags for every location as shown in Figure 15. A dump valve is mounted in-between the bag sections. As the pressure in the bag reaches the working pressure of 7 psi the valve opens and begins to fill the next bag. This arrangement allows for the sequential filling of bags from the seafloor up to the roadway deck. The volumes of the bags at different heights are shown in Table 5.

Figure 15: Beach-Slope Adaptation



The anchor foot connects to the tensioning system to keep the columns in compression after inflation. This helps to create a rigid structure. The foot also drags the bag to the bottom for filling and raises the bags for recovery. The anchor foot has a high surface area plate to create a solid surface for the columns to stand on. Also under the foot is a short pipe section. This pipe section creates a low surface area that will drive itself into the seafloor under the pressure of the lift bags to aid in anchoring the column at the base. A picture of this is shown in Figure 16.

Figure 16: Anchoring Feet



Ball-Joint System

The roadway sections use a ball-joint locking system similar to the INLS (Improved Navy Lighterage System) joint system as depicted in Figure 18 and Figure 19. The locking systems are the only steel components on the roadway deck. The operation for the joint system commences when the roadway sections are brought together; there is a three second delay where they can be joined before surface interactions move the sections apart again. To lock the sections a pneumatic piston forces a ball out and into a corresponding seat on the other section, locking them together. A pneumatic system was instead of hydraulics, as used on the INLS, because of weight. There are four piston and ball systems per section, each located at one end to ensure solid locking of the joint. Up to four sections can be connected together before surface interactions will force them apart.

Figure 17: Ball-Joint System `Diagram; Pneumatics End

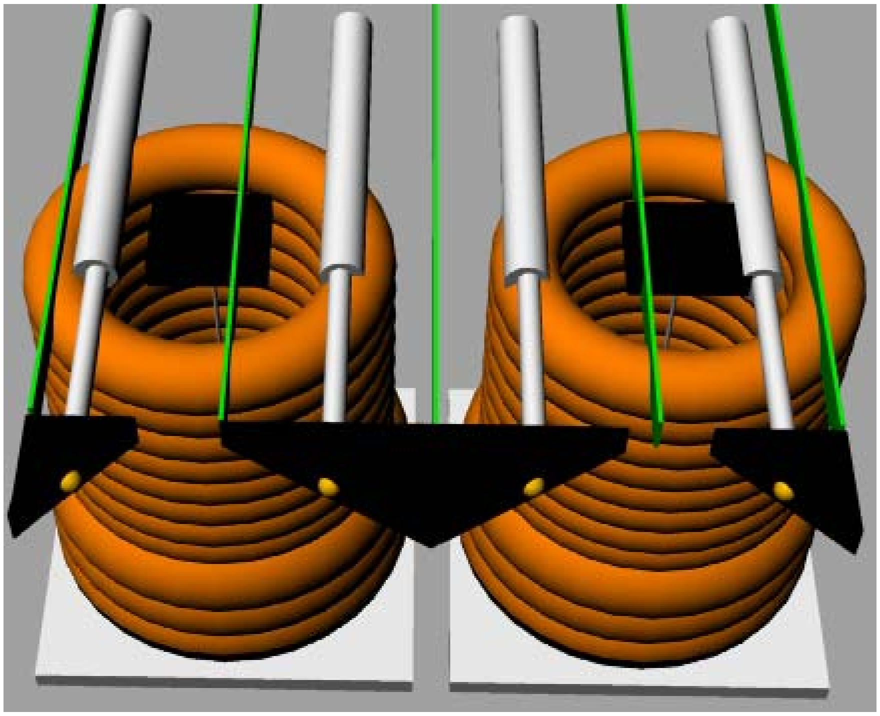
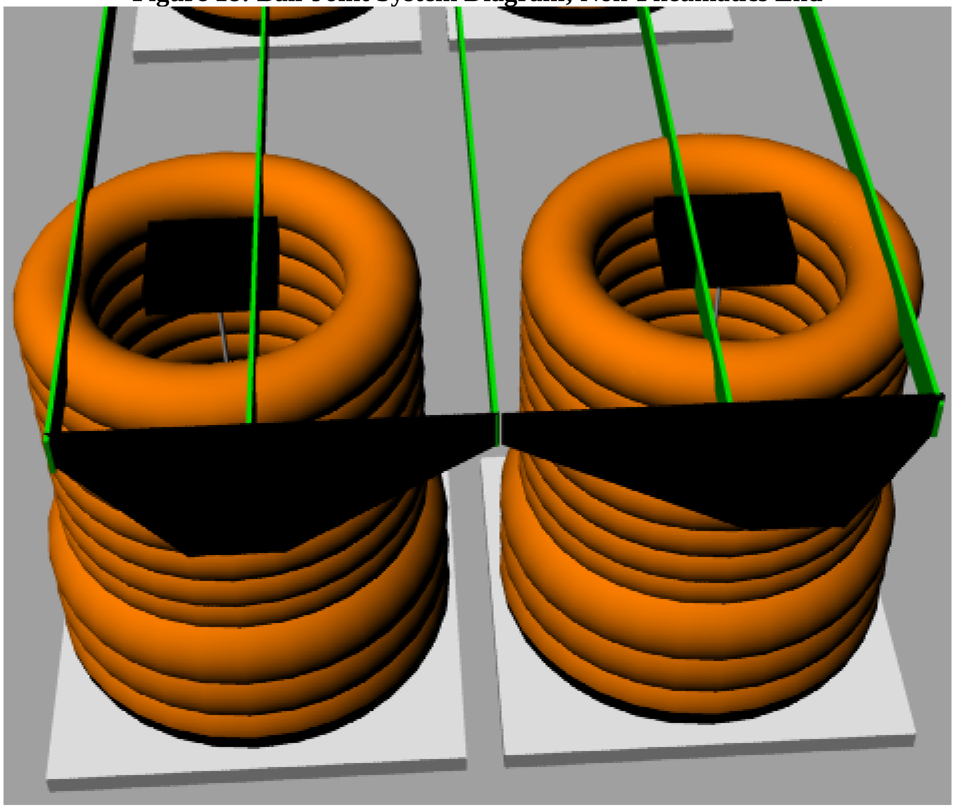


Figure 18: Ball-Joint System Diagram; Non-Pneumatics End



Size

The final dimensions of the causeway sections are 80 ft x 24 ft x 1.65 ft. This deck area is close to the current INLS so the transportation characteristics would be similar. Table 3 shows the final breakdown of weights. The final weight of the entire section is 18 long tons. The estimate is based on current vendor information and the weights of the DARC system (Deschamps Aircraft Recovery Cushion), which is the basis for the lift bag columns.

Table 3: Causeway Weight Breakdown

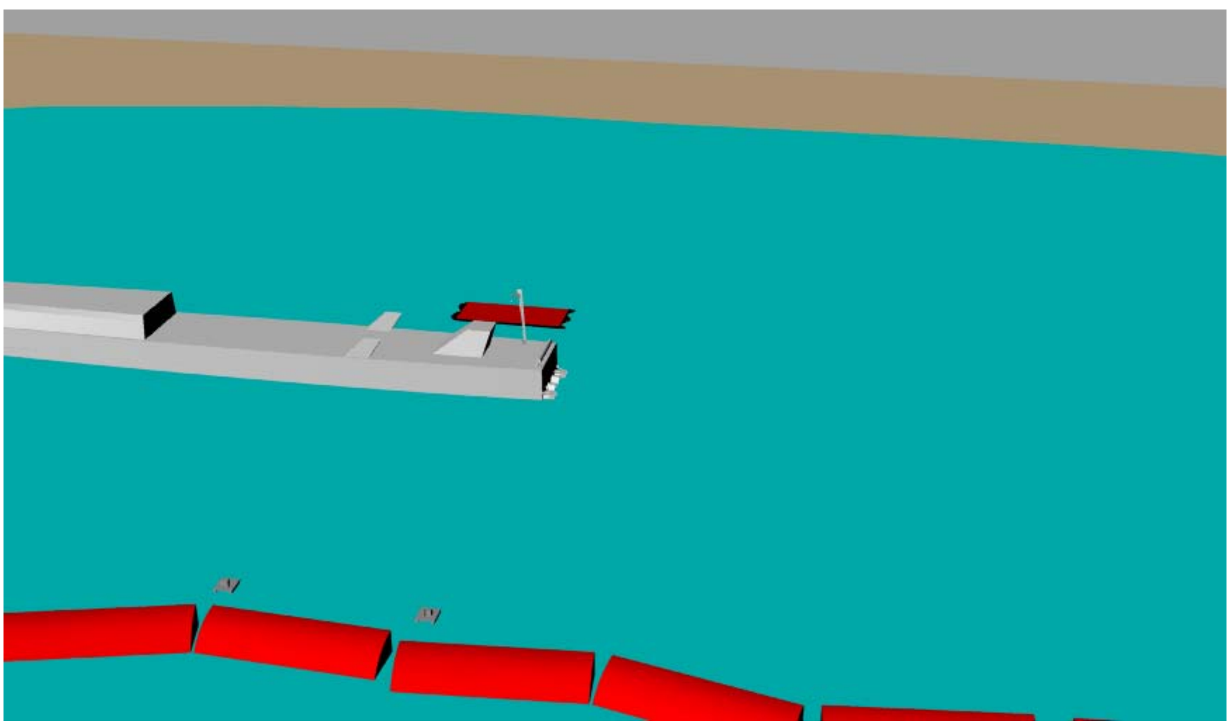
Item	Weight (lbs)	Total (lbs)	
Anchoring Foot	838	3,351	
Lift Bags	573	2,292	
Roadaway Section	34,278	34,278	
Ball-Joint Locking System	441	441	Long Tons
	Total	40,362	18

Section Size	80 ft x 24 ft x 1.65 ft
Total Propulsive Power	39 KW

Causeway Deployment

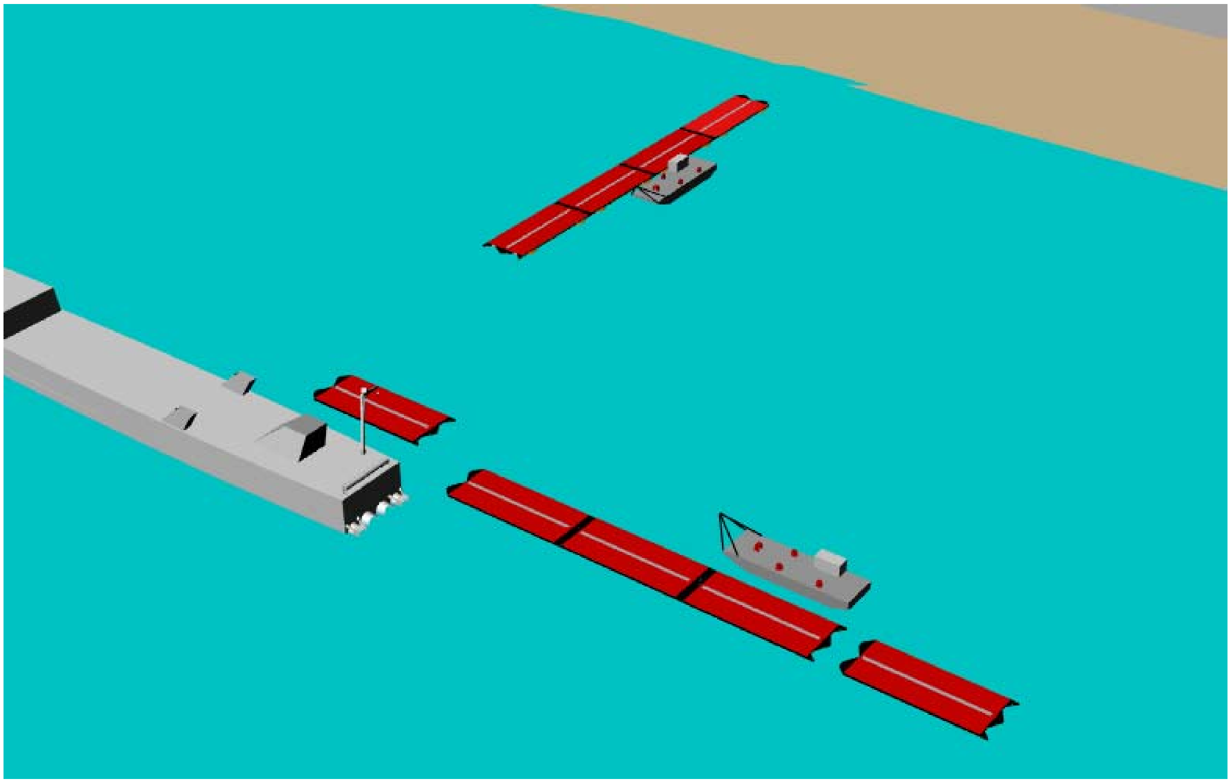
The causeway sections are transported by ship to the sheltered harbor area. The sections are craned off the deck of the ship and into the water as depicted in Figure 19 - Figure 20.

Figure 19: Step 1 of Causeway Deployment



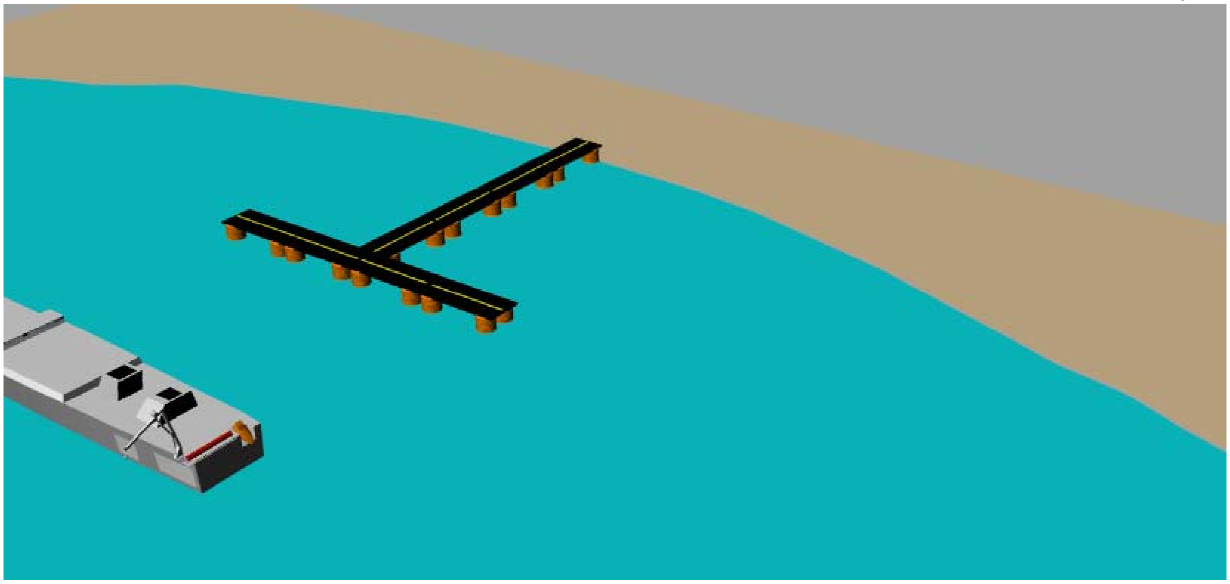
The causeway sections are maneuvered into place by a transportable INLS warping tug. The tug pushes the sections together until Ball-Joints activate automatically locking the sections together. After joining the sections are pushed into their setup positions by the warping tug as depicted in Figure 21.

Figure 20: Step 2 of Causeway Deployment



The anchors are then set and connected to the sections. The final step is to inflate the lift bag columns. The anchors and the tensioning system stiffen the columns to prevent sway of the roadway deck. When the bags are inflated and anchors tight, offload can begin.

Figure 21: Step 3 of Causeway Deployment



The method of connecting sections provides flexibility for adapting to the coastline and allows for alterative pier head configurations as shown in Figure 22, as well as including the standard trident-docking scenario shown in Figure 23. If the bags are inflated to different heights on one end, a loading ramp can be created for landing craft to drop their cargo quickly. The ramps are depicted in Figure 23.

Figure 22: Several Docking Scenarios

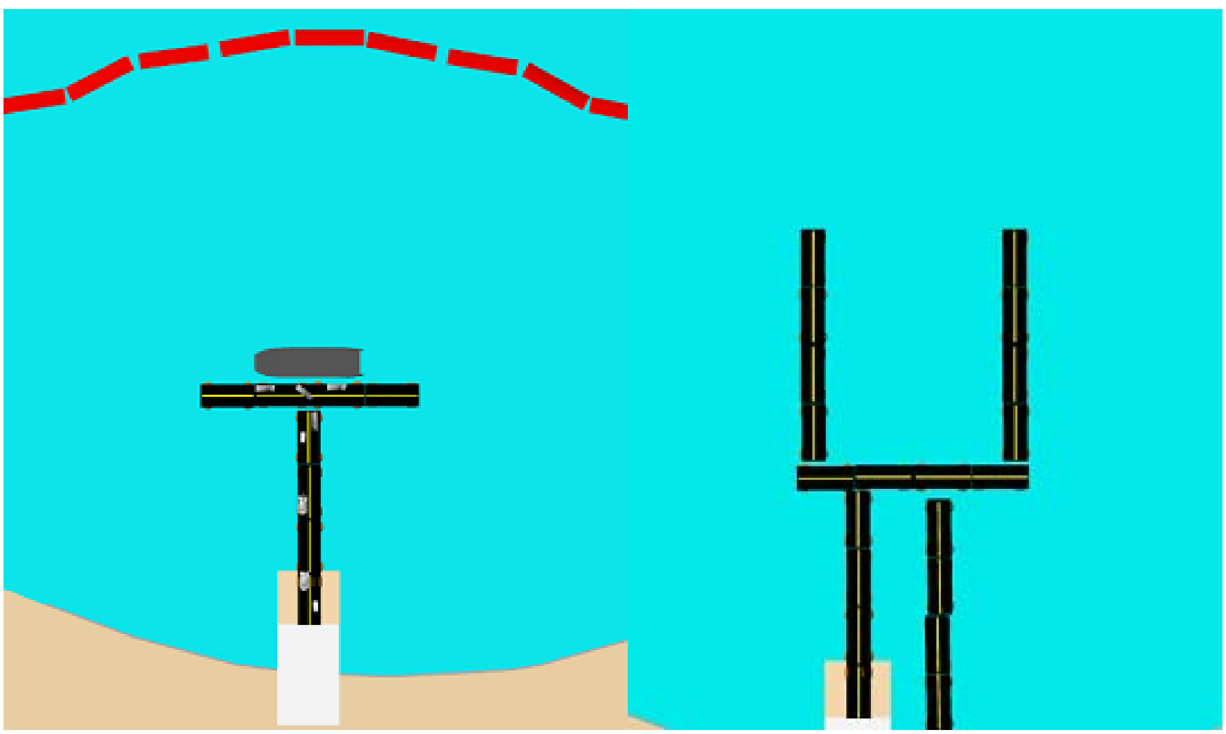
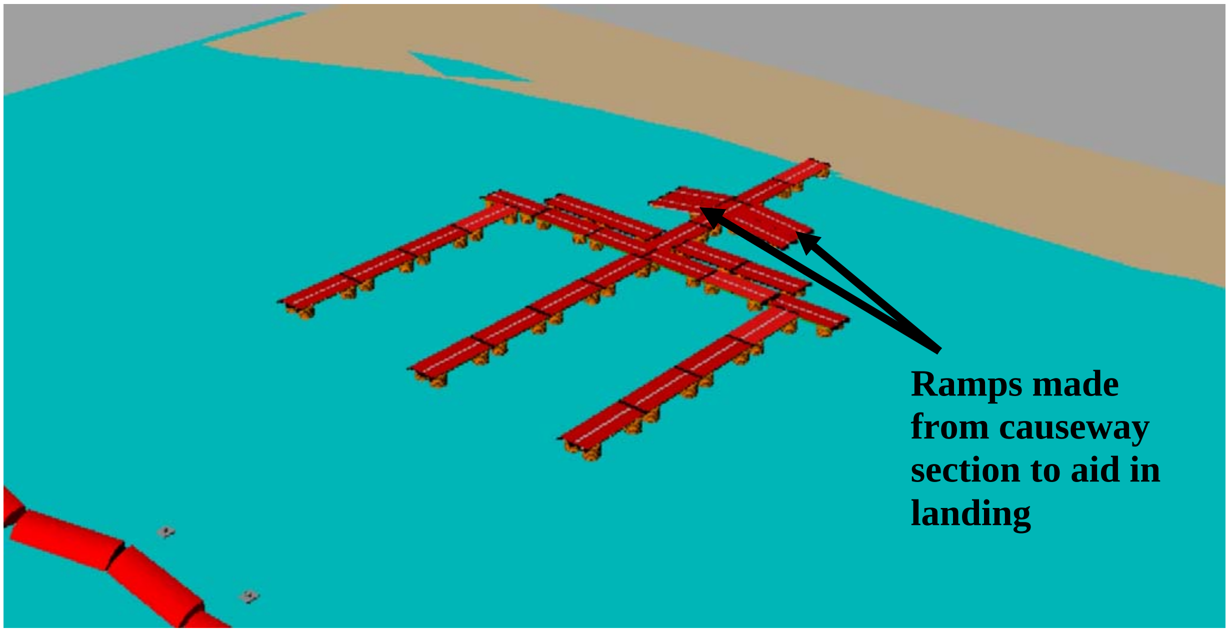


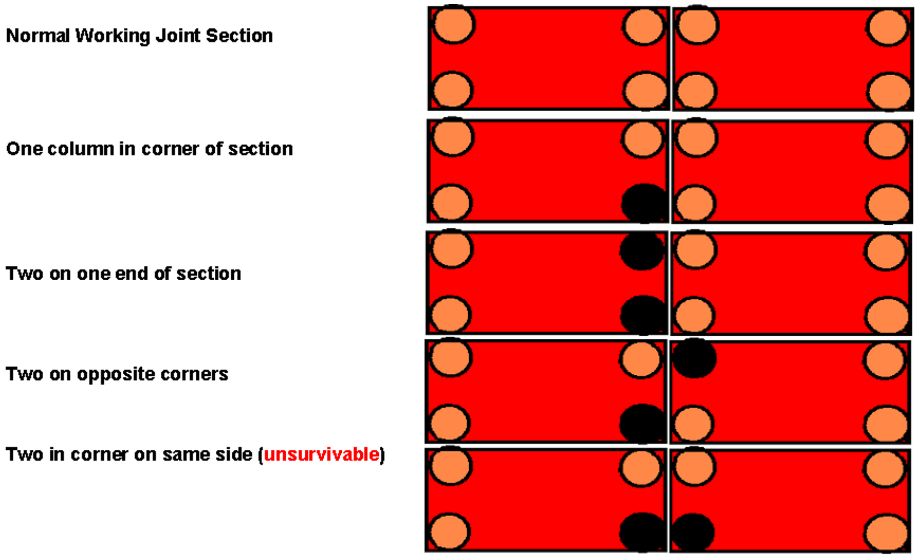
Figure 23: Trident Scenario, with Ramps



Survivability

If a column suffers damage, only the bag affected will deflate because of the dump valve system between bags on the lifting column. Several damage scenarios have been analyzed around a joint and Figure 24 presents these scenarios. The Survivability depends on both corners around a joint are supported. The joint itself will withstand the shearing force as long as both side of the joint are supported.

Figure 24: Survivability Scenarios; (Damaged Columns in Black)



Anchoring

Anchoring on the causeway is accomplished by using 5 set anchor locations to two different types of anchors, depending on the seafloor. For softer seafloors, a screw anchor has been designed. The required depth of the screw anchor is 8 meters, with a diameter of 2 feet. The anchoring scenario helps to overcome the force and moments on the columns due to wave interaction, and reduce the motions of the roadway deck. A small crew deploys the anchors. A hand held gas auger drives the anchor, until the desired depth is obtained. Another option for hard seafloors is explosively embeddable anchors. This type of anchor uses a small explosive charge to drive itself into the harder seafloors creating a firm anchoring point. The anchors are located with one in the center of the section, and the 4 others at the corners of the section, at a quarter of the length coming from the corner. Figure 25 depicts this scenario. The forces provided by screw anchors in Table 7.

Figure 25: Anchoring Arrangement

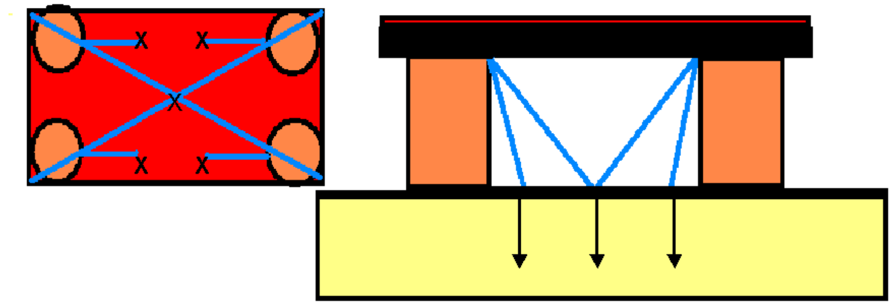
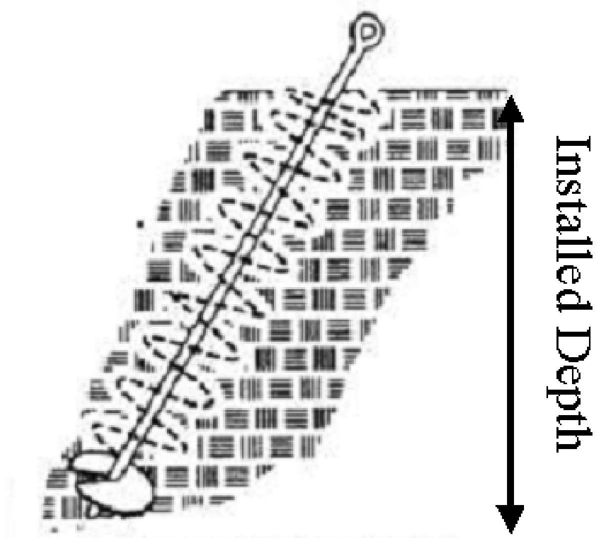


Figure 26: Screw Anchor Drawing



3.3 Model Testing

Two conceptual model tests were conducted to prove the Mulberry 21 concept. The first was the breakwater concept. Using the inflatable bag developed by the 2007 MOSES project, a miniature water filled breakwater was pressurized as pictured in Figure 28. An exercise ball represented the wavemaker in the pool. The test showed qualitatively that a water filled structure is rigid enough to create a breakwater and absorb the energy from the waves. The test also showed that the curved top of the breakwater induced the waves to break over it instead of slamming against the side of the breakwater, reducing energy to be absorbed by the breakwater.

Figure 27: Breakwater Model Test

A hybrid column of water and air was also tested as shown in Figure 29. Tubes were set up; three filled with water, two with air and put in the 140-foot model basin. The test proved the concept of the hybrid column, and that the high surface area and low pressure can support large weight. It also showed that as soon as the water column breaks the surface, the column acts as an anchor. The test also showed the need for the tensioning system. Without the column in sufficient compression, the roadway will experience motions due to wave interaction.

Figure 28: Column Model Test

4.0 Summary

Several concepts for a highly deployable harbor have been investigated and inflatable structures were chosen to facilitate deployment, installation, and recovery. Inflatable structures are light and sufficiently rigid to elevate the causeway and create a breakwater. Composite structures have high strength and are also lightweight to make the system more deployable.

A simple, lightweight, rapidly deployable and recoverable harbor system concept has been developed. The Mulberry 21 harbor system uses two sub-systems to make the whole system. The sub-systems are the breakwater and the causeway. Both incorporate new technologies and do what the original Mulberry Harbors can do in both scale and function, but allow for recoverability and portability. This is achieved by using composite technology and inflatable structures. The Mulberry 21 concept could be a valuable asset for cargo unloading in the future Navy and has the flexibility to adapt to changing theaters. The final working harbor is shown in Figure 29.

There are several risks involved with using the concepts presented in this report. One is the Supreme Protector's adhesion process. The rubber-coated material has not been tested in the heat sealing and sewing processes.

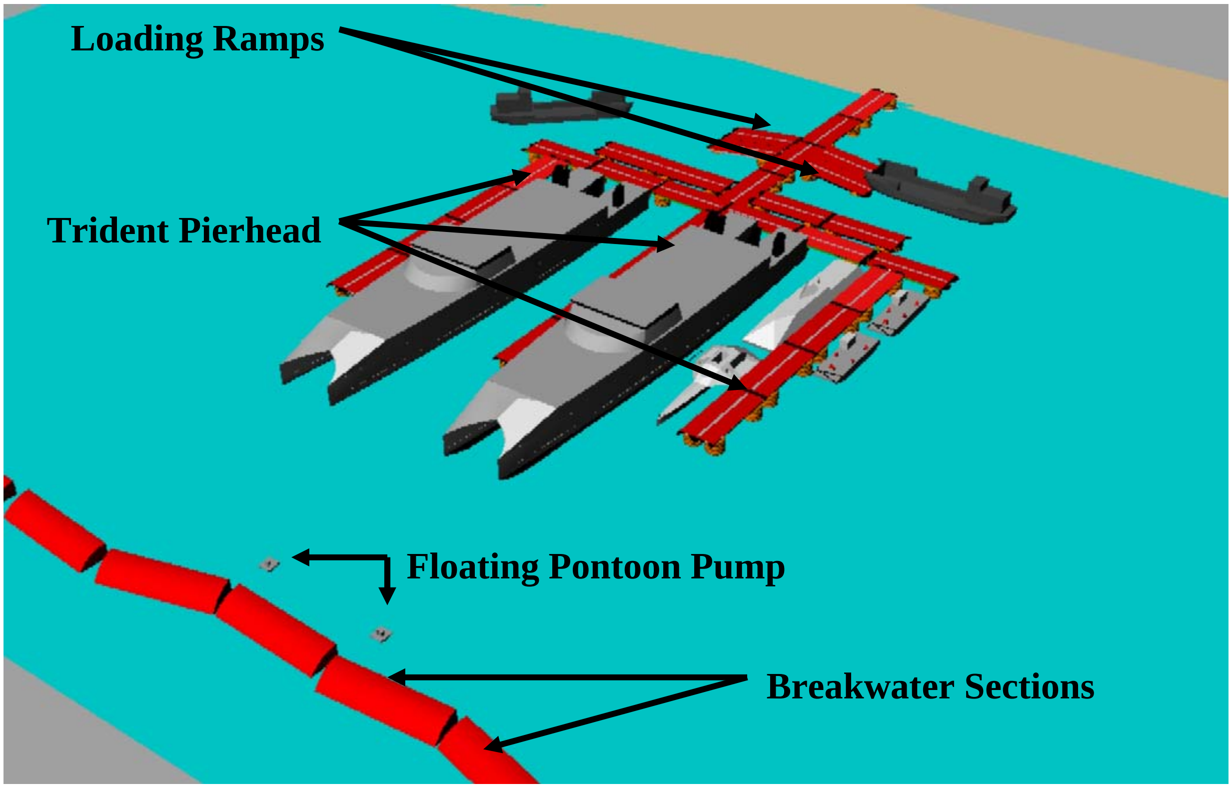
Another is the fact that the original lift bag concept was developed from the Deschamps Aircraft Recovery Cushion, or DARC system. This has not been designed and demonstrated for a marine application, nor was it intended for a hybrid system, as it is only filled with air.

Recommendations for Future Work

There are several features in the Mulberry 21 that need further design development work to create a fully operational system. One is to develop better anchoring operations, such as investigating embeddable explosive anchors further for hard surface anchoring. Also the filling sequence should be developed. While a filling sequence has been devised, a system that could raise all columns at once could be developed.

Scale model tests should be conducted on both the breakwater and causeway to test storm survivability. Materials should also be tested to show that they could be used for this application such as the DARC system in a marine environment and the adhesion process recommended by Supreme Protector.

Figure 29: Final Harbor Illustration



Appendix A

Table 4: Wave Energy Calculations; (Based on McCormick).

Sea State	Sig Wave Height (Meters)	Ave. length of Waves (Meters)	Wave Number (m^-1)	Energy Flux	Total Energy (J/m)	Wave Speed (m/s)	tons
0.00	0.50	2.00	3.14	12.24	7.67	3.20	0.04
1.00	0.50	9.50	0.66	26.69	7.67	6.98	0.04
2.00	2.00	26.00	0.24	706.39	122.68	11.55	0.66
3.00	3.50	50.00	0.13	3,000.78	375.71	16.01	2.04
4.00	6.00	80.00	0.08	11,276.81	1,104.14	20.24	5.98
5.00	8.00	130.00	0.05	27,754.52	1,962.91	25.49	10.64
6.00	18.00	220.00	0.03	215,171.40	9,937.24	31.10	53.85

7.00	32.00	400.00	0.02	957,852.04	31,406.59	35.33	170.20
8.00	52.00	650.00	0.01	2,878,235.32	82,933.03	36.93	449.43
9.00	80.00	1,000.00	0.01	7,166,850.89	196,291.20	37.57	1,063.74

Table 5: Volume based on Inflated Height of Column

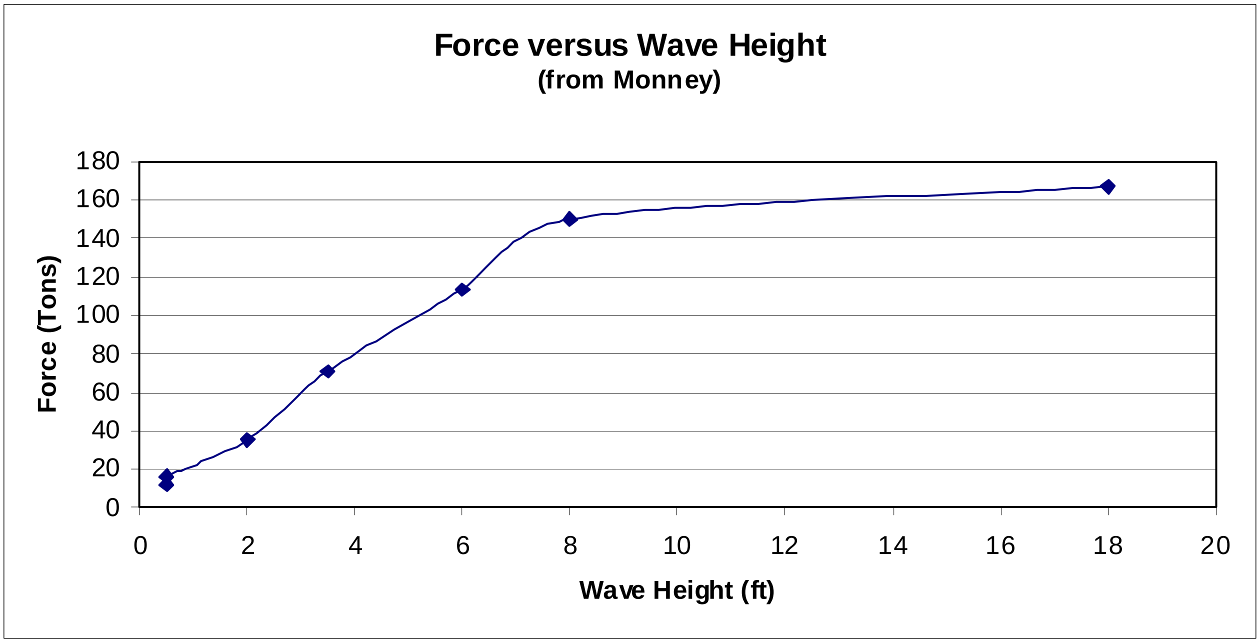
Column Volumes							
height m	Height ft	Volume m^3	Volume ft^3	Height m	Height ft	Volume m^3	Volume ft^3
0.00	0.00	0.00	0.00	4.40	14.44	58.09	0.00
0.40	1.31	5.28	186.50	4.80	15.75	63.37	186.50
0.80	2.62	10.56	372.99	5.20	17.06	68.65	372.99
1.20	3.94	15.84	559.49	5.60	18.37	73.93	559.49
1.60	5.25	21.12	745.99	6.00	19.69	79.22	745.99
2.00	6.56	26.41	932.49	6.40	21.00	84.50	932.49
2.40	7.87	31.69	1118.98	6.80	22.31	89.78	1118.98
2.80	9.19	36.97	1305.48	7.20	23.62	95.06	1305.48
3.20	10.50	42.25	1491.98	7.60	24.93	100.34	1491.98
3.60	11.81	47.53	1678.48	8.00	26.25	105.62	1678.48
4.00	13.12	52.81	1864.97	8.40	27.56	110.90	1864.97
4.40	14.44	58.09	2051.47	8.80	28.87	116.18	2051.47

Table 6: Pressure Differential based on Exposed Breakwater, to show Survivability

Depth	Height out of the water	Pressure difference at water line (Pa)	Pressure difference at water line (psi)
0.0	45.0	137,917.8	-20.0
2.0	43.0	131,788.1	-19.1
4.0	41.0	125,658.4	-18.2
6.0	39.0	119,528.8	-17.3
8.0	37.0	113,399.1	-16.4
10.0	35.0	107,269.4	-15.6
12.0	33.0	101,139.7	-14.7
14.0	31.0	95,010.0	-13.8
16.0	29.0	88,880.4	-12.9

18.0	27.0	82,750.7	-12.0
20.0	25.0	76,621.0	-11.1
22.0	23.0	70,491.3	-10.2
24.0	21.0	64,361.6	-9.3
26.0	19.0	58,232.0	-8.4
28.0	17.0	52,102.3	-7.6
30.0	15.0	45,972.6	-6.7
32.0	13.0	39,842.9	-5.8
34.0	11.0	33,713.2	-4.9
36.0	9.0	27,583.6	-4.0
38.0	7.0	21,453.9	-3.1
40.0	5.0	15,324.2	-2.2
42.0	3.0	9,194.5	-1.3
44.0	1.0	3,064.8	-0.4
46.0	-1.0	-3,064.8	0.4

Figure 30: Water Force and Moment Calculation; Interaction between Columns



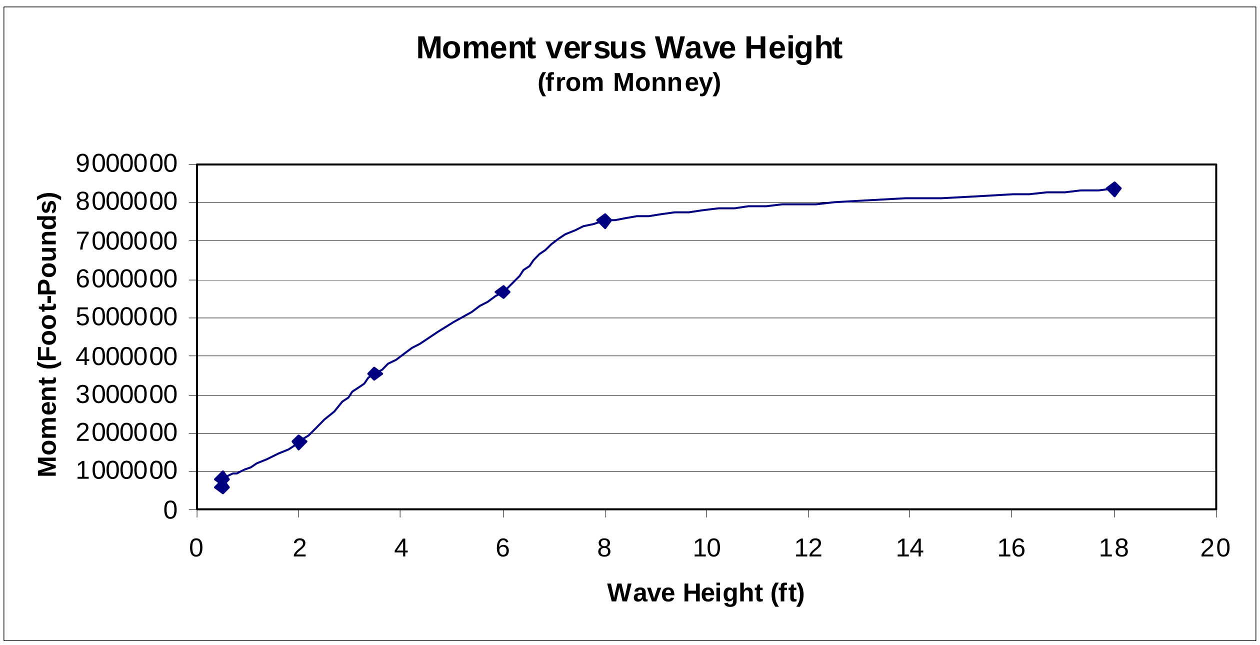


Table 7: Force of Screw Anchor based on Depth

Screw	Mass of	Force (N)	Force	Force	Force

Anchor Depth	Sand (kg)		(lbs)	(LT)	(st)
1	2,423	23,766	5,343	2	3
2	3,634	35,650	8,014	4	4
2	4,845	47,533	10,686	5	5
3	6,057	59,416	13,357	6	7
3	7,268	71,299	16,029	7	8
4	8,479	83,182	18,700	8	9
4	9,691	95,066	21,372	10	11
5	10,902	106,949	24,043	11	12
5	12,113	118,832	26,715	12	13
6	13,325	130,715	29,386	13	15
6	14,536	142,598	32,057	14	16
7	15,747	154,482	34,729	16	17
7	16,959	166,365	37,400	17	19
8	18,170	178,248	40,072	18	20
8	19,381	190,131	42,743	19	21
9	20,593	202,014	45,415	20	23
9	21,804	213,898	48,086	21	24
10	23,015	225,781	50,758	23	25
10	24,227	237,664	53,429	24	27
11	25,438	249,547	56,100	25	28
11	26,649	261,430	58,772	26	29
12	27,861	273,314	61,443	27	31
12	29,072	285,197	64,115	29	32
13	30,283	297,080	66,786	30	33
13	31,495	308,963	69,458	31	35
14	32,706	320,846	72,129	32	36
14	33,917	332,730	74,801	33	37
15	35,129	344,613	77,472	35	39
15	36,340	356,496	80,144	36	40
16	37,551	368,379	82,815	37	41
16	38,763	380,262	85,486	38	43
17	39,974	392,146	88,158	39	44
17	41,185	404,029	90,829	41	45
18	42,397	415,912	93,501	42	47

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